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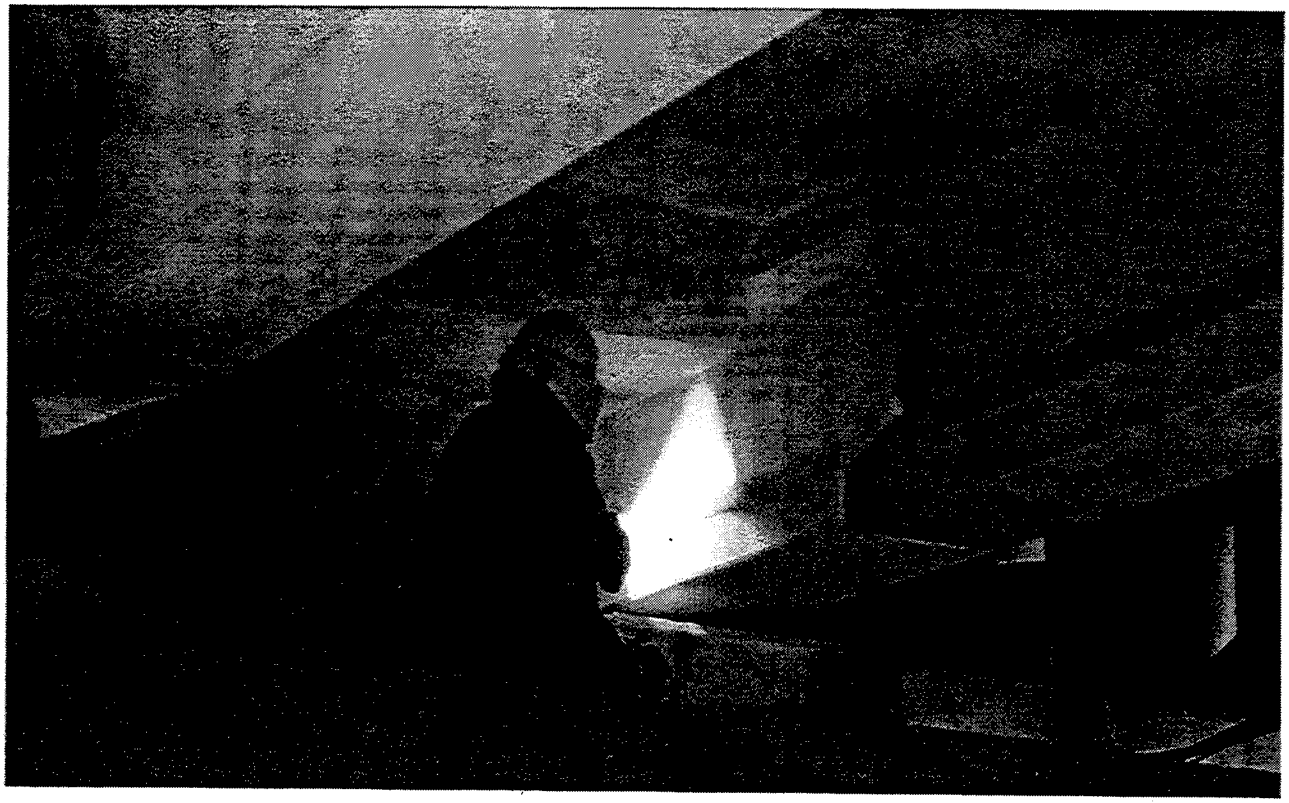
EVALUATION OF SPRAYED-ON METALIZING FOR PRECAST PRESTRESSED CONCRETE I-BEAMS



INNOVATIVE BRIDGE RESEARCH CONSTRUCTION (IBRC) PROGRAM

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16. Abstract

Cathodic protection has been used as an effective means of arresting corrosion in reinforced concrete. A galvanic system typically consists of a sacrificial anode, some form of adhesive or fastening system to secure the anode to the concrete, and a electrical connection between the anode and the corroded reinforcement. No external power or complex monitoring system is required. Galvanic systems are recognized for their simplicity and ability to operate with little or no maintenance for the life of the system. This research was conducted to evaluate "sprayed-on" galvanic cathodic protection systems as a means of extending the life of precast prestressed concrete I-beams. By arresting corrosion, the galvanic system can extend the life of the prestressing strands and reinforcing steel, postponing or minimizing the need for repairing structural members of the bridge. The Illinois Department of Transportation, Bureau of Materials and Physical Research (IDOT BMPR) conducted an evaluation of three different types of zinc-based metals as anodes for galvanic cathodic protection. The anodes were "metallized" onto the faces of several pre-cast, pre-stressed concrete I-beams of twin structures, west of Peoria, Illinois. This study was conducted to evaluate the metallizing process, and the different metals as anodes for consideration as alternative methods for galvanic cathodic protection. Evaluation of the three different types of "spray on" anodes for galvanic cathodic protection indicate that the systems do not offer any improved amount of protection to the pre-stressing strands when compared to beams that were not treated. Results from the corrosion potential surveys indicate that the systems are not protecting the steel. It appears that the anodes do not develop enough current necessary to drive the ion exchange to arrest the corrosion process.

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EVALUATION OF SPRAYED-ON METALIZING FOR PRECAST PRESTRESSED CONCRETE I-BEAMS

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April 2002

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DISCLAIMERS

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Introduction

Cathodic protection has been used as an effective means of arresting corrosion in reinforced concrete. Active systems (impressed current) as well as passive systems (galvanic) have been used to reduce the effects of corrosion. Impressed current systems use external power to drive ion exchanges causing a repassification of the protective oxide layer formed at the reinforcing bar (rebar)-concrete interface. Drawbacks to impressed current systems are the cost and physical requirements for external power and monitoring of the system.

A galvanic system typically consists of a sacrificial anode, some form of adhesive or fastening system to secure the anode to the concrete, and a electrical connection between the anode and the corroded reinforcement. No external power or complex monitoring system is required. Galvanic systems are recognized for their simplicity and ability to operate with little or no maintenance for the life of the system.

This research was conducted to evaluate "sprayed-on" galvanic cathodic protection systems as a means of extending the life of precast prestressed concrete I-beams. By arresting corrosion, the galvanic system can extend the life of the prestressing strands and reinforcing steel, postponing or minimizing the need for repairing structural members of the bridge.

The Illinois Department of Transportation, Bureau of Materials and Physical Research (IDOT BMPR) conducted an evaluation of three different types of zinc-based metals as anodes for galvanic cathodic protection. The anodes were "metallized" onto the faces of several pre-cast, pre-stressed concrete I-beams of twin structures, west of Peoria, Illinois. This study was conducted to evaluate the metallizing process, and the different metals as anodes for consideration as alternative methods for galvanic cathodic protection.

Supporting Research

IDOT has four active impressed current cathodic protection systems throughout the state. Their performance has been somewhat limited due to continued operational problems. The titanium mesh, which is placed in a deck overlay, is prone to damage when patches are installed. Lightening strikes or current surges have disabled rectifiers and modems used for power distribution and communications. Recently, there has been a move to investigate the performance of cheaper, more reliable galvanic systems. In addition to the metallized system evaluated in this study, IDOT has evaluated the following passive cathodic protection systems.

3M Corporation, 4727 Zinc Hydrogel Anode

In 1998, the Products Evaluation Unit of IDOT BMPR began an evaluation of a galvanic cathodic protection system marketed by the 3M Corporation. Known as 4727 Zinc Hydrogel Anode, the system consisted of a 10-mil thick sheet of zinc foil coated with a 30-mil thick, ionically conductive, pressure sensitive adhesive hydrogel. A protective liner was placed on the back of the hydrogel/zinc assembly as it was rolled during production to prevent self-corrosion of the zinc.

Two sites in Peoria, Illinois were chosen in April of 1998 as the first test sites. One site was a pier-cap of a roadway overpass along I-74, while the other site included parts of two structures carrying I-474 over a township road. The system was relatively easy to install. It required an electrical connection to the reinforcing steel, and a clean, dry concrete surface. During installation the protective liner was peeled away and the anode was firmly pressed onto the concrete surface. The anode was placed on a pier cap for each structure as well as at the abutment end of two prestressed, precast portland cement concrete I-beams. The anode was placed over a length of 40 inches, from the end of the beam. The beams included one fascia (outside) beam and one interior beam. A corrosion potential survey was conducted to determine the amount of active corrosion occurring at each location. After the survey was completed, the concrete surfaces were power-washed and allowed to dry before the anode was installed. The locations of the corrosion potential test sites were reestablished to monitor the performance of the anode. In September of 1998, a third site was established south of Lincoln, Illinois. The anode was placed on the abutment ends of twin structures carrying I-55 over the Spring Creek overflow channel. The anode was placed on each structure's fascia beams, for a total of eight test locations at the site. Installation proceeded as at the earlier sites, with four corrosion potential monitoring sites established on the outside of each fascia beam. Periodic monitoring continued at each site.

Periodic evaluations in 1998, 1999 and 2000 of the beam ends at the Peoria sites indicated that the systems did conform to the NACE (National Association of Corrosion Engineers) specification of a 100 mV depolarization over 4 hours after the electrical circuit had been broken. However, it was noted where the anode was placed on the outside of the fascia beams and in areas exposed to water from leaking joints, it was beginning to separate from the face of the precast concrete. The hydrogel in these areas had become brittle and had lost its adhesive and conductive properties. Resistance tests on pieces of the brittle hydrogel indicated that it had become an insulator rather than a conductor.

The anode installed at Lincoln, Illinois was observed on September 2, 1998; October 22, 1998; August 5, 1999; and July 7, 2000. Performance during the early observations had also initially conformed to the NACE recommended practice. However, evaluation of the anode on August 5, 1999 revealed similar performance to that occurring in Peoria. The zinc had become debonded from the surface of the concrete in areas exposed to water. The July 7, 2000 evaluation revealed the debonded areas had enlarged as the anode dried out. Fragments of the anode could be seen on the slope wall in addition to visible gaps between the zinc and the concrete. The failure of the hydrogel resulted in a termination of the study.

Vector Corrosion Technology, Galvashield.
Vector Corrosion Technologies of Winnipeg, Manitoba, Canada, manufactures Galvashield, a palm sized, puck shaped, galvanic zinc core surrounded by a high pH mortar. Tie wires secured to the zinc core provide the mechanical and electrical connections to reinforcing steel. IDOT BMPR Products Evaluation Unit began a field evaluation of Galvashield in June, 2001 in which several anodes were installed on bridge pier repairs and joint repairs associated with a bridge carrying IL 10 over Sugar Creek west of Lincoln, Illinois. The evaluation is expected to continue to 2004.

Description of Study

In August of 2000, IDOT BMPR conducted an evaluation of three different types of zinc based metals for use as a "spray on" form of galvanic cathodic protection. The study was conducted to evaluate "sprayed-on" galvanic cathodic protection as a means of extending the life of pre-cast pre-stressed concrete I-beams, so that repairs to critical areas such as beam webs and flanges, sole plates, and other corrosion prone areas are minimized.

The metals were applied to the ends of several Portland cement concrete pre-cast, pre-stressed I-beams, by a thermal spray (metallizing) process. Once the anodes were applied, they were electrically connected to the reinforcing steel of the beams, completing the cathodic protection circuits. Corrosion potentials of the beams were monitored and compared to untreated (control) beams to determine the effectiveness of the cathodic protection system.

The metals evaluated included pure zinc, as well as two zinc alloys; an 85/15% blend of zinc and aluminum and a proprietary blend of zinc, aluminum, and indium. The experimental feature was conducted at the north abutments of the twin structures (Structure Number 072-0116 & 072-0117) carrying Interstate 474 over Pottstown Road in Peoria, Illinois. The structures were constructed in 1978 and rehabilitated in 2000, with new joints and nosings on the bridge decks

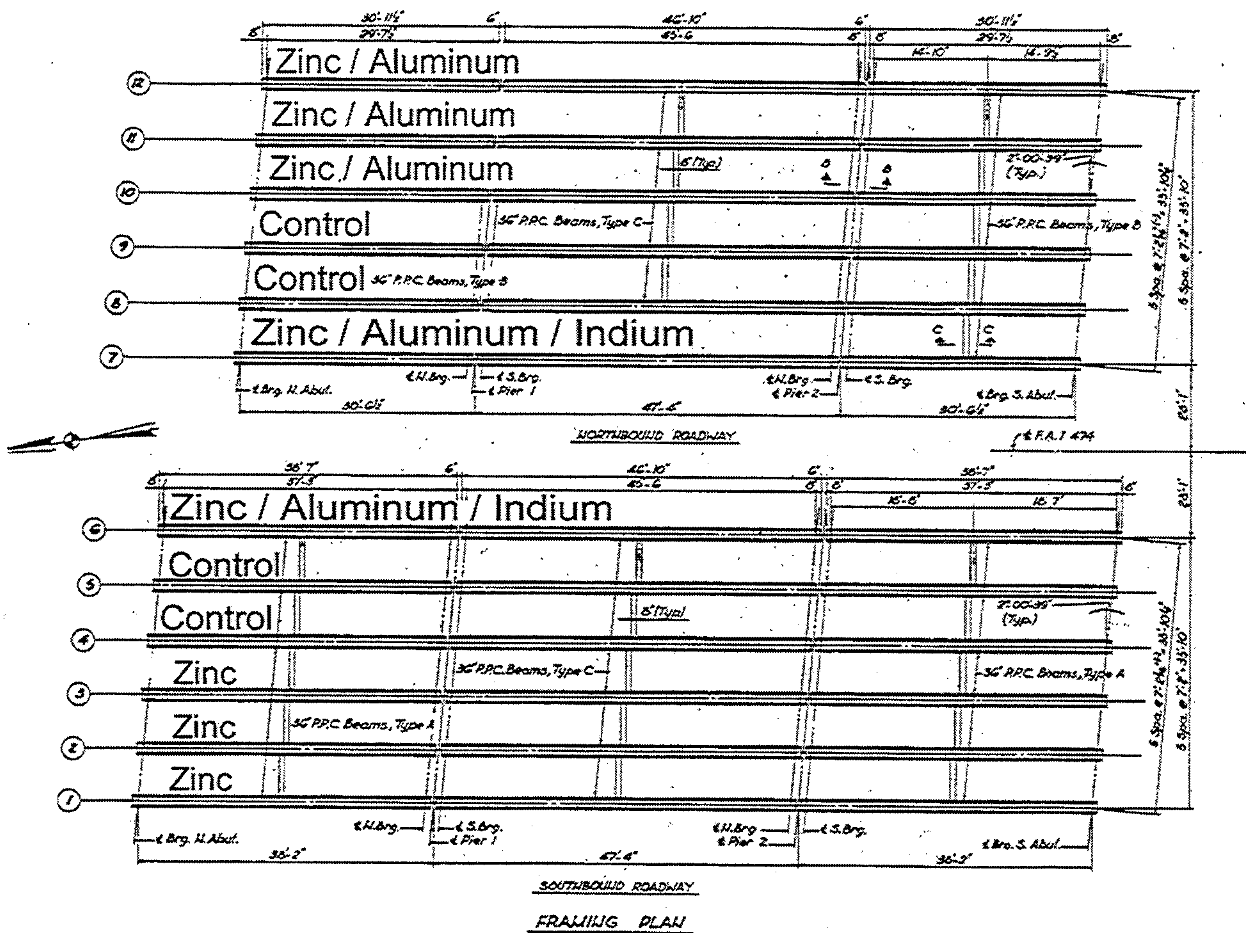

Figure 1. Framing Plan of twin structures. Note description of anode applied to north end of beams.

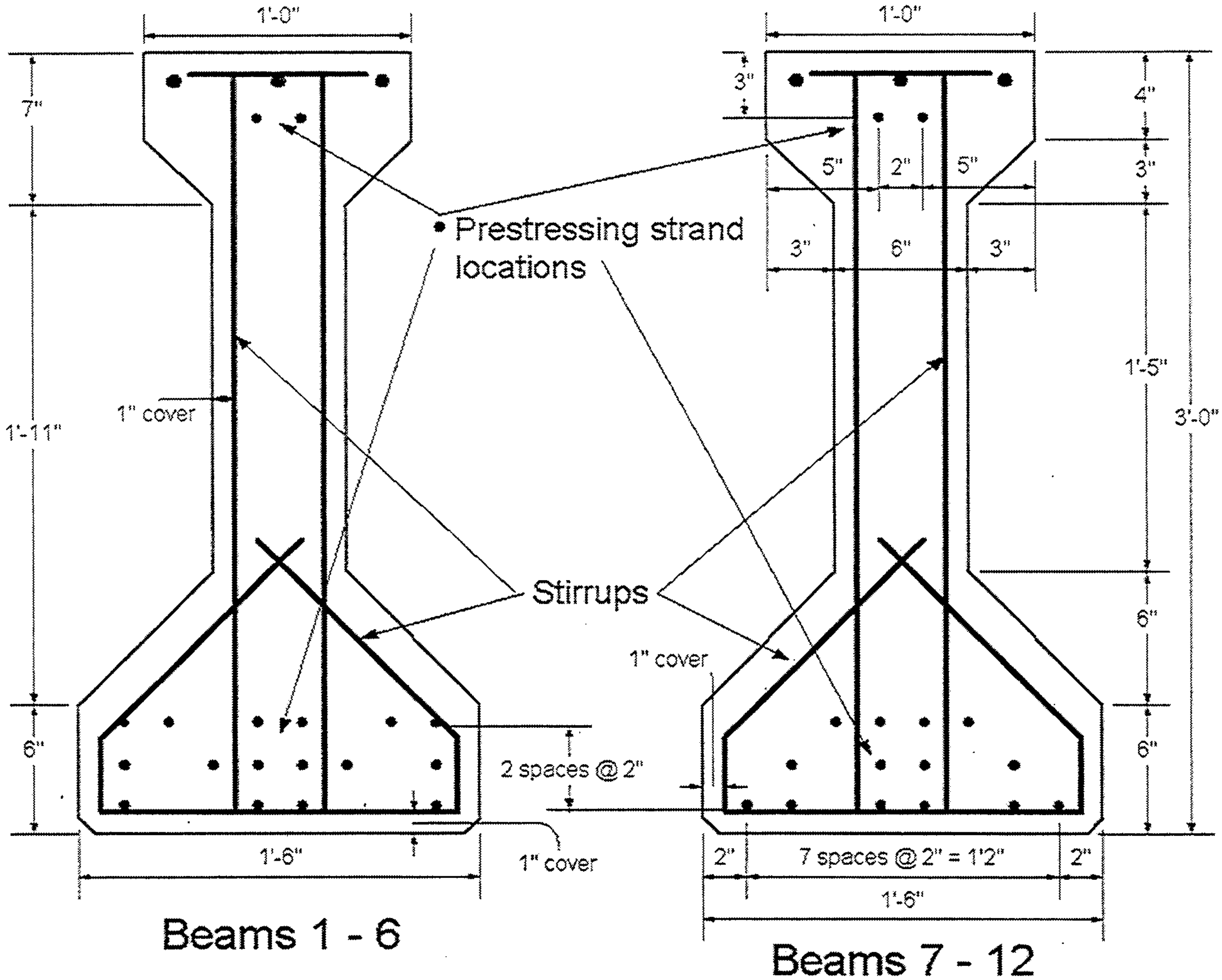

Figure 2. Beam cross sections detailing stirrup and pre-stressing strand locations.

Structure No. 072-0116 (West Structure, Beams 1-6, southbound I-474)

Beam Number	Type of metal applied
1	Zinc
2	Zinc
3	Zinc
4	Control
5	Control
6	Zinc/Aluminum/Indium

Structure No. 072-0117 (East Structure, Beams 7-12, northbound I-474)

Beam Number	Type of metal applied
7	Zinc/Aluminum/Indium
8	Control
9	Control
10	Zinc/Aluminum
11	Zinc/Aluminum
12	Zinc/Aluminum

Table 1. Anode location description.

and approach slabs. The different anodes were applied to the concrete I-beams as displayed in Figure 1 and listed in Table 1. Figure 2 displays a cross section of the two different types of I-beams, revealing the different locations of the pre-stressing strands.

Preparation began with power washing a five foot section at the abutment end of each of the twelve beams. The washing helped remove surface dirt and debris. Attempts were made to establish an electrical connection to the pre-stressing strands at the end of the beams. However it was not possible, due to the small amount of space between the end of the beams and the abutment wall (< 4 inches).

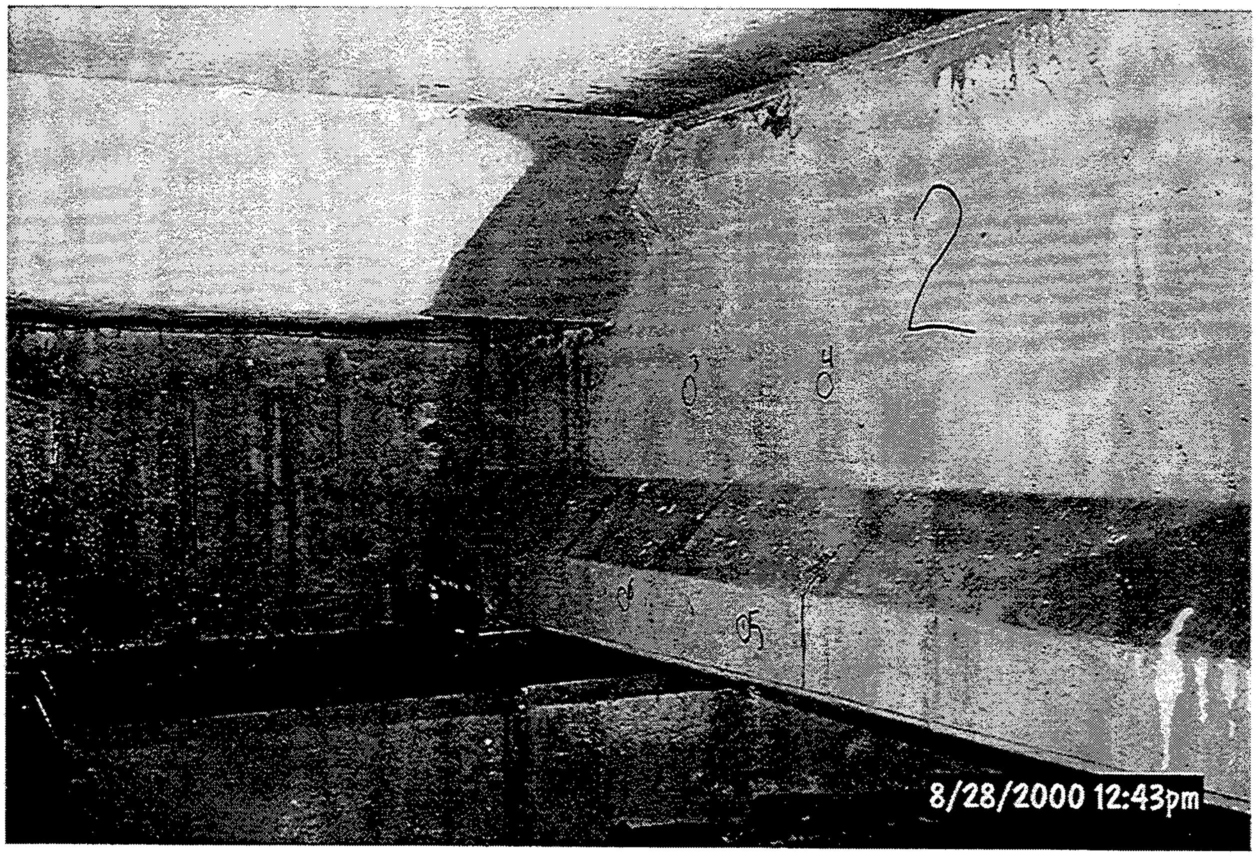

Photo 1. Power washed beam #6 with corrosion potential sites located. Note test locations detailed by numbered circles.

An electrical connection was to be made to a stirrup since it was in contact with all of the outer pre-stressing strands. A vertical stirrup was initially located in each beam based on design details in the plans. A series of 1 inch diameter holes were drilled in the beam to expose part of the stirrup through the concrete cover. Once uncovered, electrical continuity was established between the exposed outer pre-stressing strands and the stirrup. In order to make an easier electrical connection, continuity was also established between the bearing plate and the stirrup. It was determined that it would be easier to drill and tap a connection into the bearing plate, rather than make a connection to the stirrup. Once continuity was established, the holes in the beam were filled with patching grout. Initial corrosion potential measurements were obtained at eight locations across the beam (twelve for each fascia beam) using a copper-copper sulfate half cell. Test locations were mapped and identified so they would not be covered with the anodes. Test locations, as identified in Photo 1 and Figure 3, were located six inches up from the taper on the web, and at mid-height of the vertical face of the flange. Four additional test sites were placed on the inclined surface of the flange on the outside surfaces of the fascia beams (beam # 1, 6, 7, and 12). Test locations and limits of the work are detailed in Figure 3.

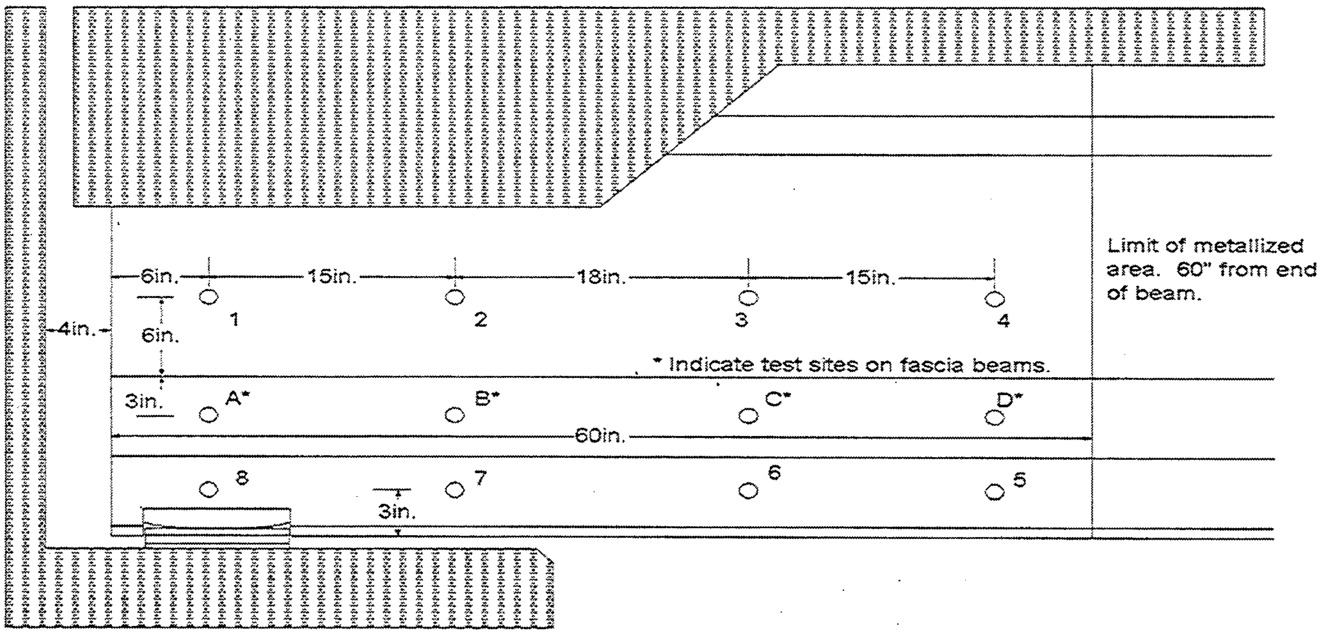

Figure 3. Metallized area on beams and corrosion potential test sites. Letter sites on fascia beams only.

Photo 2. Removing concrete cover from stirrup.

Beam surfaces to be metallized were lightly brush blasted with sharp, angular, non-metallic abrasive to remove a small amount of surface concrete, which may have been contaminated with salts (sulfates, nitrates or phosphates) or other debris. After blasting, the surfaces were inspected for tie wires and other metal fragments which were exposed on the beam surfaces. These areas, as well as the corrosion potential test sites, were covered with heat resistant tape prior to metallizing. The exposed wires were covered to prevent forming an electrical short between the anode and the reinforcing steel.

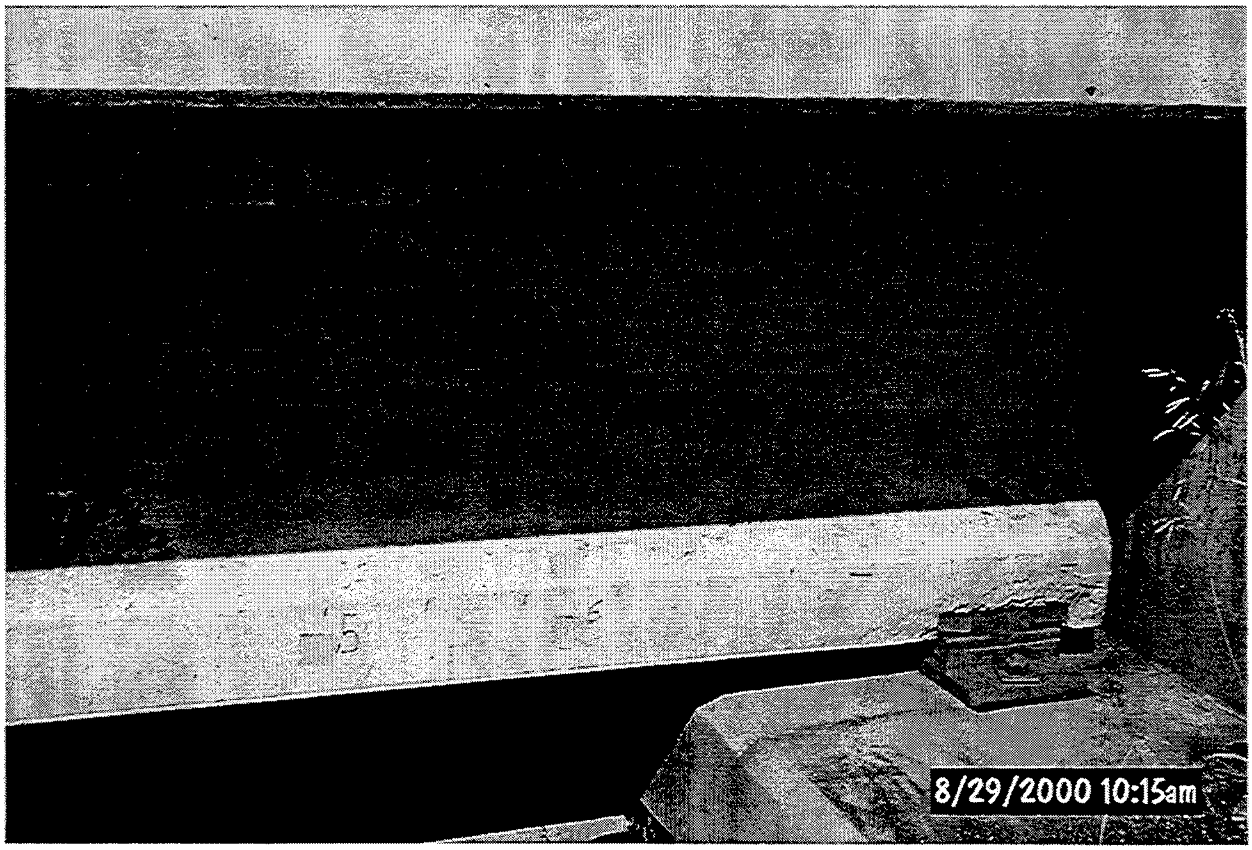

Photo 3. Beam #6, east side w/fiber tape cover over corrosion potential sites and exposed metal tie wires.

The metallized process applied the anode to the concrete substrate by feeding the particular wire into a plasma stream. The stream, consisting of an electric arc fed by compressed air, instantly melted the wire and sprayed it on the substrate where it cooled and adhered to the surface. Cooling was instantaneous, negating any thermal expansion of the substrate, leading to a tight bond between the anode and the substrate. Each anode was applied in two passes applied at 90° to each other. Each pass applied approximately 3 mils of anode, Zn or Zn/Al to the surface. The Zn/Al/In anode was applied using a slower rate, applying approximately 6 mils per pass.

A four inch square piece of expanded steel plate was attached to the surface of each beam before the second coat of anode was applied. The plate was welded to an electrical wire. This was to be attached to the bearing plate, completing the circuit. After the second coat of anode was metallized, a non-conductive epoxy was used to cover the perimeter edges of the plate and wires leading from the plate to the bearing. An electrical junction box was placed on the beam to house a junction in the wire from the plate to the bearing. The banana clip connection was to be used when monitoring the system. The plate and wire were coated with epoxy in an attempt to make the system as tamper resistant as possible. The tape was removed from the covered areas, although in some areas the tape came off of the concrete during the metallizing process and some of the corrosion potential test sites were lost. Once the electrical connections were made, the system became powered and was allowed to stabilize.

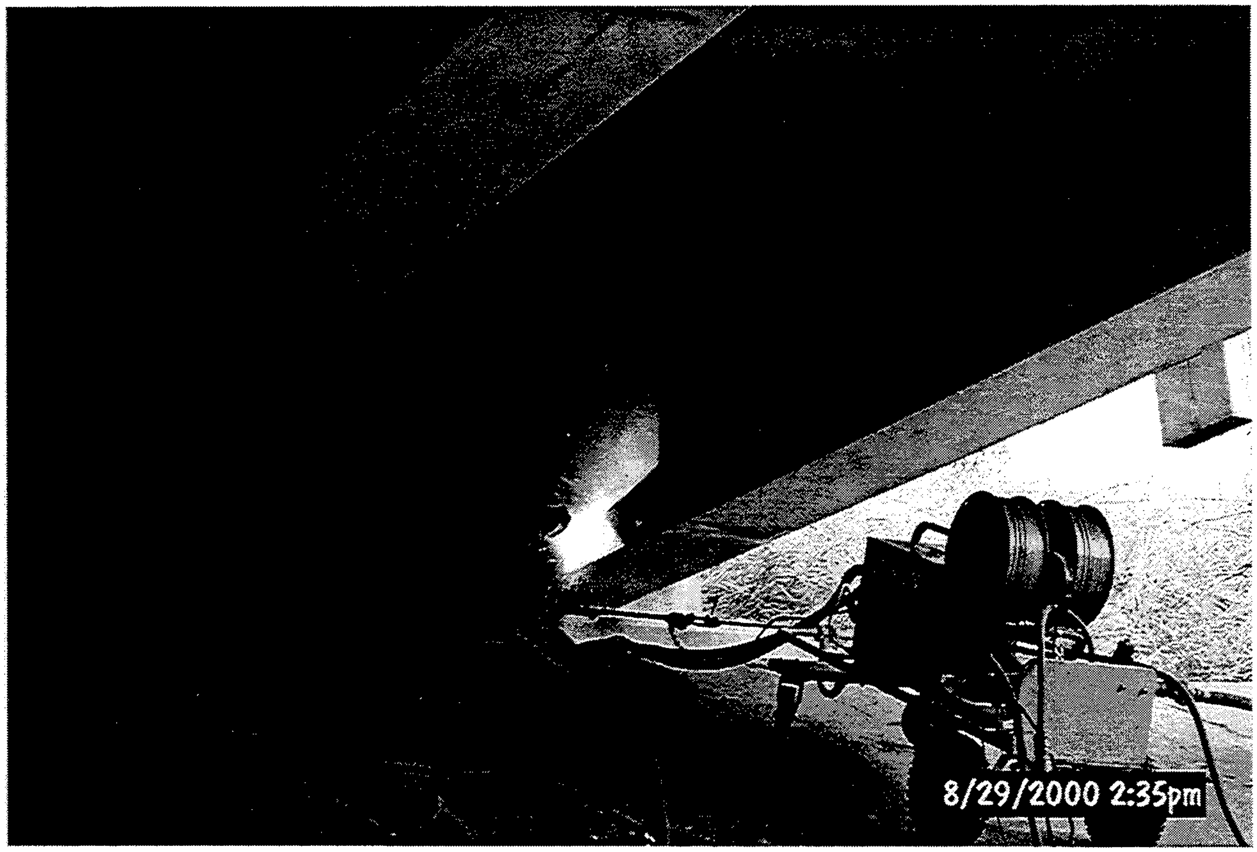

Photo 4. Metallizing beam #6 with Zn/Al/In anode.

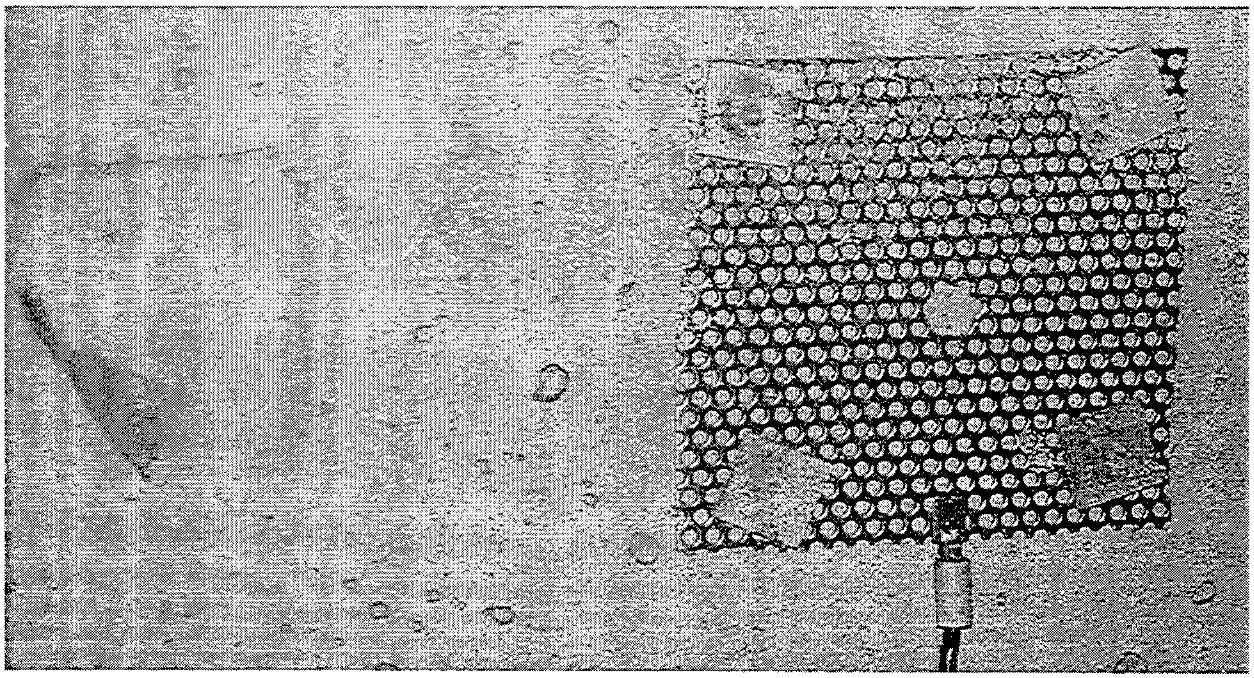

Photo 5. Expanded steel plate before second metallizing pass. Note loose tape on left.

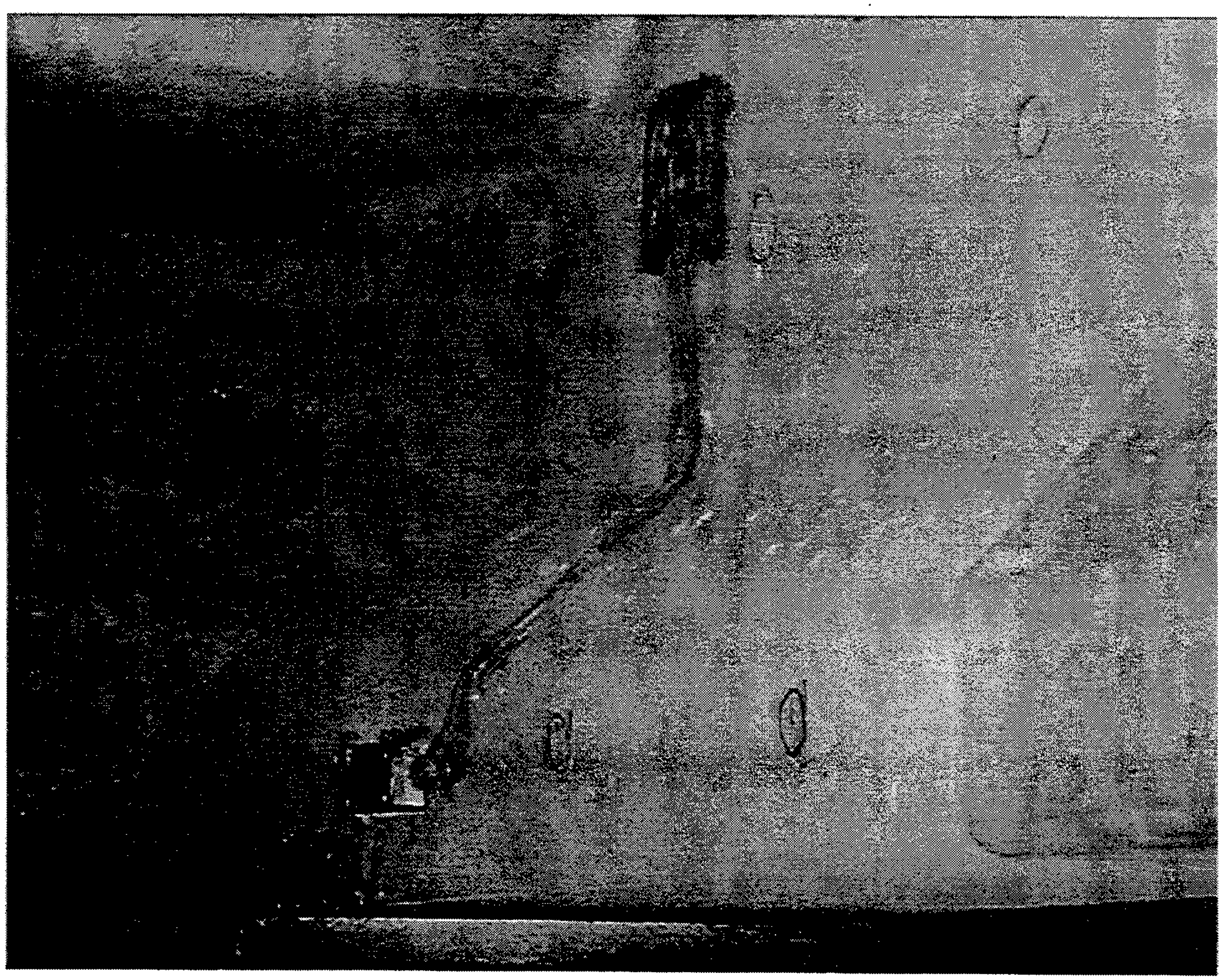

Photo 6. Plate and wire covered with epoxy..

Results and Discussion of their Significance

A corrosion potential survey was conducted on the beams on October 31, 2001. Results of the survey were compared to the initial corrosion potential values obtained in the August 28, 2000 pre-installation survey. The survey was conducted in accordance with ASTM C-876 the "Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete." Corrosion potentials were measured with a copper-copper sulfate half cell. Results are presented in Table 2.

Test Location		1	2	3	4	5	6	7	8	A	B	C	D
Beam 1	8/28/00	-0.228	-0.025	0.075	0.102	0.128	0.070	-0.006	-0.277	0.125	0.069	0.023	-0.264
Zinc	10/31/01	-0.651	-0.076	-0.029	0.060	-0.001	-0.174	-0.228	NA	-0.752	-0.144	-0.236	-0.334
outside	Δ	-0.423	-0.051	-0.104	-0.042	-0.129	-0.244	-0.222	NA	-0.877	-0.213	-0.259	-0.070
	8/28/00	-0.185	-0.002	0.062	0.125	0.143	0.115	0.048	-0.226				
inside	10/31/01	NA	NA	-0.046	-0.062	-0.230	-0.021	-0.300	-0.240				
	Δ	NA	NA	-0.108	-0.187	-0.373	-0.136	-0.348	-0.014				
Beam 2	8/28/00	-0.506	-0.492	-0.139	-0.111	-0.086	-0.128	-0.410	-0.497				
Zinc	10/31/01	NA	-0.637	-0.048	-0.002	-0.054	-0.005	-0.040	NA				
	Δ	NA	-0.145	0.091	0.109	0.032	0.123	0.370	NA				
Beam 3	8/28/00	-0.624	-0.449	-0.346	-0.332	-0.269	-0.287	-0.352	-0.464				
Zinc	10/31/01	-0.517	-0.167	-0.068	-0.039	-0.005	-0.001	-0.065	NA				
	Δ	0.107	0.282	0.278	0.293	0.264	0.286	0.287	NA				
Beam 4	8/28/00	-0.657	-0.517	-0.241	-0.188	-0.177	-0.208	-0.404	-0.567				
Control	10/31/01	-0.581	-0.487	-0.213	-0.159	-0.162	-0.179	-0.373	-0.523				
	Δ	0.076	0.030	0.028	0.029	0.015	0.029	0.031	0.044				
Beam 5	8/28/00	-0.415	-0.328	-0.061	0.003	-0.018	-0.059	-0.285	-0.394				
Control	10/31/01	-0.363	-0.295	0.010	0.035	0.023	0.010	-0.179	-0.319				
	Δ	0.052	0.033	0.071	0.032	0.041	0.069	0.106	0.075				
Beam 6	8/28/00	-0.260	-0.112	0.097	0.154	0.202	0.166	-0.086	-0.150				
Zn/Al/Id	10/31/01	-0.652	-0.264	0.113	0.196	0.115	0.108	NA	-0.286				
inside	Δ	-0.392	-0.152	0.016	0.042	-0.087	-0.058	NA	-0.136				
outside	8/28/00	-0.192	0.021	0.110	0.098	0.120	0.098	0.037	-0.216	0.114	0.101	0.051	-0.158
	10/31/01	-0.402	-0.044	0.144	0.051	-0.001	-0.008	-0.242	-0.273	NA	-0.008	-0.226	-0.272
	Δ	-0.210	-0.065	0.034	-0.047	-0.121	-0.106	-0.279	-0.057	NA	-0.109	-0.277	-0.114

Table 2. Corrosion Potential Survey Results.

Test Location		1	2	3	4	5	6	7	8	A	B	C	D
Beam 7	8/28/00	-0.247	0.039	0.094	0.107	0.125	0.082	-0.014	-0.273	0.115	0.077	-0.007	-0.259
Zn/Al/Id	10/31/01	-0.393	-0.170	-0.111	-0.113	-0.165	-0.166	-0.227	-0.346	-0.068	NA	-0.201	-0.330
outside	Δ	-0.146	-0.209	-0.205	-0.220	-0.290	-0.248	-0.213	-0.073	-0.183	NA	-0.194	-0.071
inside	8/28/00	-0.239	-0.138	0.080	0.123	0.144	0.107	-0.146	-0.185				
	10/31/01	-0.365	-0.509	-0.095	-0.059	-0.034	-0.058	-0.397	-0.347				
	Δ	-0.126	-0.371	-0.175	-0.182	-0.178	-0.165	-0.251	-0.162				
Beam 8	8/28/00	-0.476	-0.331	-0.135	-0.092	-0.085	-0.115	-0.300	-0.380				
Control	10/31/01	-0.418	-0.326	-0.096	-0.082	-0.081	-0.077	-0.260	-0.380				
	Δ	0.058	0.005	0.039	0.010	0.004	0.038	0.040	0.000				
Beam 9	8/28/00	-0.210	-0.064	-0.027	-0.003	0.053	0.040	0.000	-0.124				
Control	10/31/01	-0.335	-0.176	-0.128	-0.093	-0.045	-0.043	-0.065	-0.192				
	Δ	-0.125	-0.112	-0.101	-0.090	-0.098	-0.083	-0.065	-0.068				
Beam 10	8/28/00	-0.258	-0.201	-0.185	-0.169	-0.141	-0.146	-0.131	-0.210				
85/15 Zn/Al	10/31/01	-0.084	-0.015	-0.051	-0.019	-0.032	0.008	-0.027	-0.004				
	Δ	0.174	0.186	0.134	0.150	0.109	0.154	0.104	0.206				
Beam 11	8/28/00	-0.267	-0.208	-0.038	-0.004	0.041	-0.042	-0.199	-0.347				
85/15 Zn/Al	10/31/01	-0.852	-0.847	-0.605	NA	-0.523	-0.625	-0.754	-0.889				
	Δ	-0.585	-0.639	-0.567	NA	-0.564	-0.583	-0.555	-0.542				
Beam 12	8/28/00	-0.260	-0.130	-0.042	-0.031	0.008	-0.016	-0.104	-0.357				
85/15 Zn/Al	10/31/01	-0.278	-0.135	-0.063	-0.041	-0.037	-0.090	-0.043	NA				
inside	Δ	-0.018	-0.005	-0.021	-0.010	-0.045	-0.074	0.061	NA				
outside	8/28/00	-0.303	-0.153	-0.073	-0.054	0.011	-0.089	-0.096	-0.374	-0.007	-0.081	-0.088	-0.316
	10/31/01	-0.337	-0.205	-0.063	-0.073	-0.704	-0.164	NA	NA	0.033	-0.105	-0.137	NA
	Δ	-0.034	-0.052	0.010	-0.019	-0.715	-0.075	NA	NA	0.040	-0.024	-0.049	NA

Table 2. Corrosion Potential Survey Results. (continued.)

Once the corrosion potentials were tabulated and compared to initial values, the following overall conclusions could be drawn about the performance of the anodes:

- None of the anodes displayed an improvement (reduction in the change of the corrosion potential) when compared to the control beams to warrant additional testing.

- The corrosion potential at the test site was highly influenced by the location of the test site relative to "available water." This would include rain on the fascia beams, water from leaking joints, or cracks in the bridge deck itself. In areas with more available water, the corrosion potentials were much higher, indicating that the anode did not have enough driving power to overcome the corrosion process.

Results from individual beams are discussed below

Beams 1, 2 , and 3 were sprayed with an anode composed of 100% zinc. Beam 1 was a fascia beam on the west-side of the west structure (SN 072-0116). Evaluation of the corrosion potentials show values higher than those for the control beams (Beams 4 and 5) for that structure. Even though the outside of the beam was exposed to more water than other locations, corrosion potentials for locations 2, 3, 4, 5, and D for beam 1 show values similar to those of the control beams, indicating that corrosion is more active at locations 1, 6, 7, B, and C. Location A is not considered valid and will be discussed later. Values for the inside of Beam 1 show corrosion potentials higher than those of the control beams, somewhat in line with the same locations on the outside of the beam. A higher rate of corrosion would be expected in a fascia beam compared to the interior beams.

Values for Beams 2 and 3 show a higher rate of corrosion occurring at the bottom test locations as opposed to those on top, as well as at locations closer to the end of the beams than further in the beams. This is somewhat expected since water entering the beams from leaks in the joints would collect at the exposed ends of the pre-stressing strands. More would tend to collect at the bottom of the beam than at the top as it ran down the web and collected at the exposed ends of the pre-stressing strands. Photo 7 shows evidence of zinc oxide (a corrosion product) forming on the surface of the zinc anode where water has run down the surface of the beam.

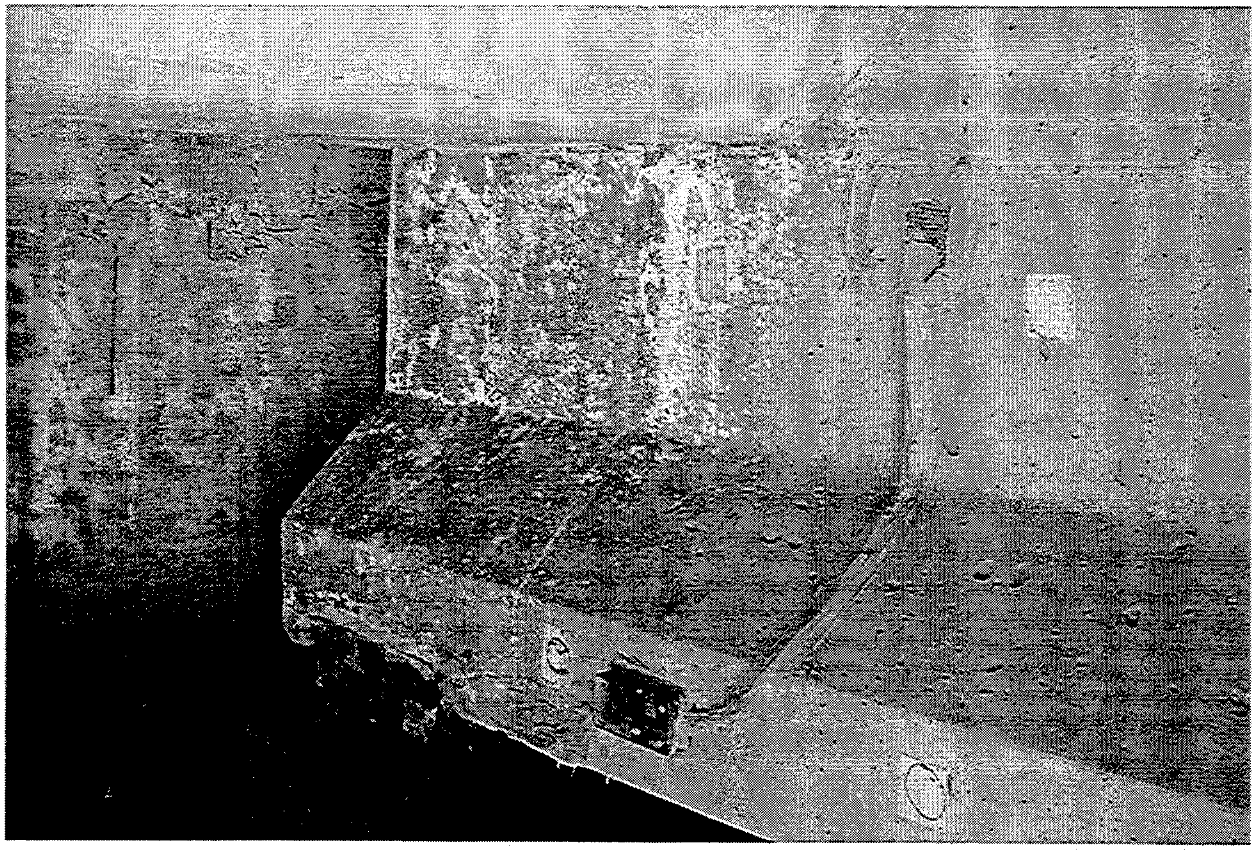

Photo 7. Beam 2 west side Zn/Al anode corrosion products.

Beams 4 and 5 (control beams) show small changes in the corrosion potentials compared to the other beams, possibly due to the intact deck joint preventing water form migrating into the beams. The two beams show the least amount change in corrosion potentials compared to the treated beams. Photo 8 shows evidence of very little water running down the face of beam 4.

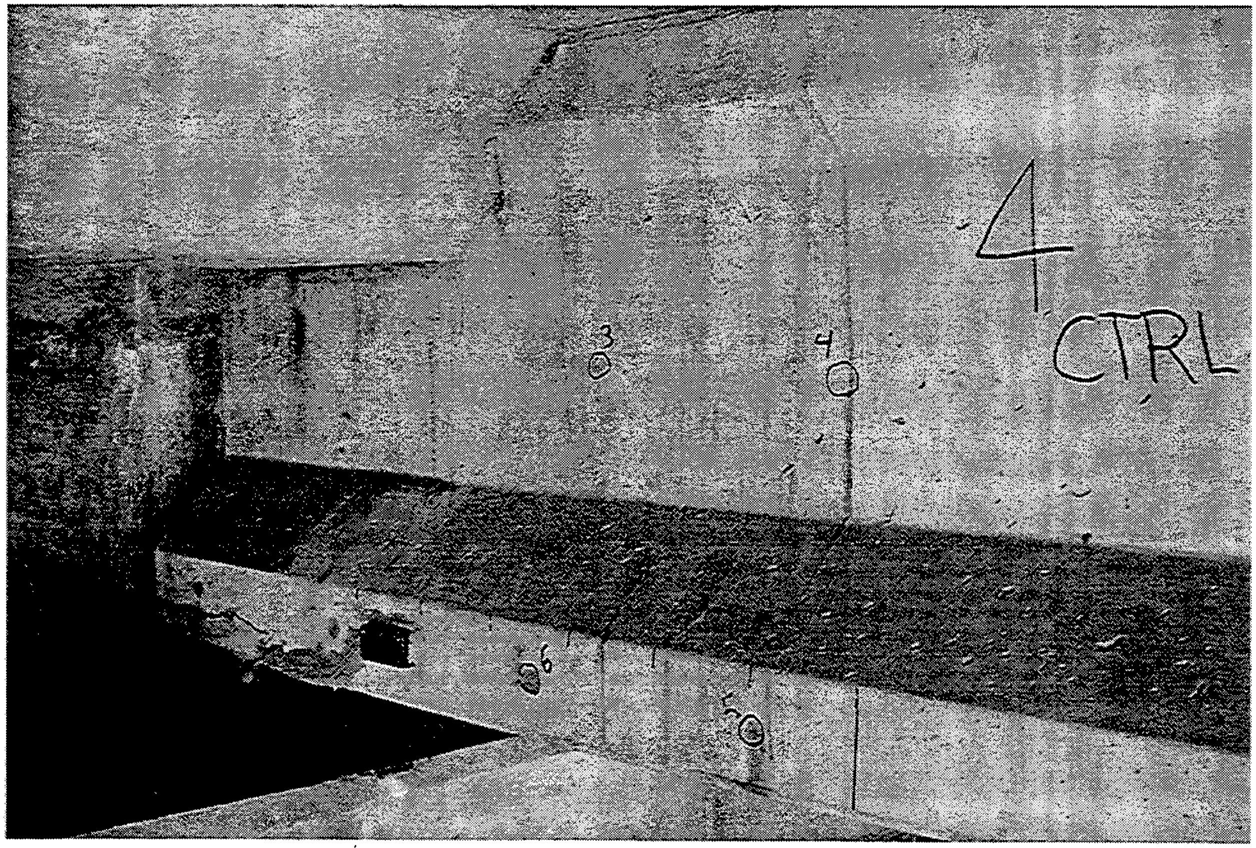

Photo 8. West side of Beam 4. Little evidence of water running down the face of the beam.

Beams 6 and 7 were treated with the Zinc/Aluminum/Indium anode developed by Corrpro Company. Corrpro claims that the indium will keep the anode active in drier, less humid conditions. Results for beam 6 follow performance of the other treated beams in that high corrosion potential differences exist at locations 1, 2, 7, and 8 with lower differences at locations 3, 4, 5, and 6. Outside locations on beam 6 are somewhat inconclusive. Beam 7 shows higher differences on the outside as a fascia beam (West side of east structure SN#072-0117). The inside of beam 7 is inconclusive, yet has higher corrosion potentials on the inside than most of the other beams.

Beams 8 and 9 are control beams on the eastern bridge and are similar in performance to beams 4 and 5, with low differences in corrosion potentials compared to the treated beams.

Beams 10, 11, and 12 were treated with an anode composed of 85% zinc and 15% aluminum. Beam 11 shows unrealistically high readings. This may be due to active corrosion occurring at the strands or may be in part due to an electrical short occurring between the zinc anode and the copper/copper sulfate half cell due to a small amount of water applied to the surface of the concrete per ASTM C-876. This is similar to what may have occurred at test site A on Beam 1.

Beam 10 shows corrosion potentials which are somewhat higher than the control beams, possibly due to leaking joints. Photo 9 shows the corrosion products. Beam 12 shows corrosion potentials much lower than the control beams. These values, again are somewhat unrealistic for a fascia beam exposed to rain.

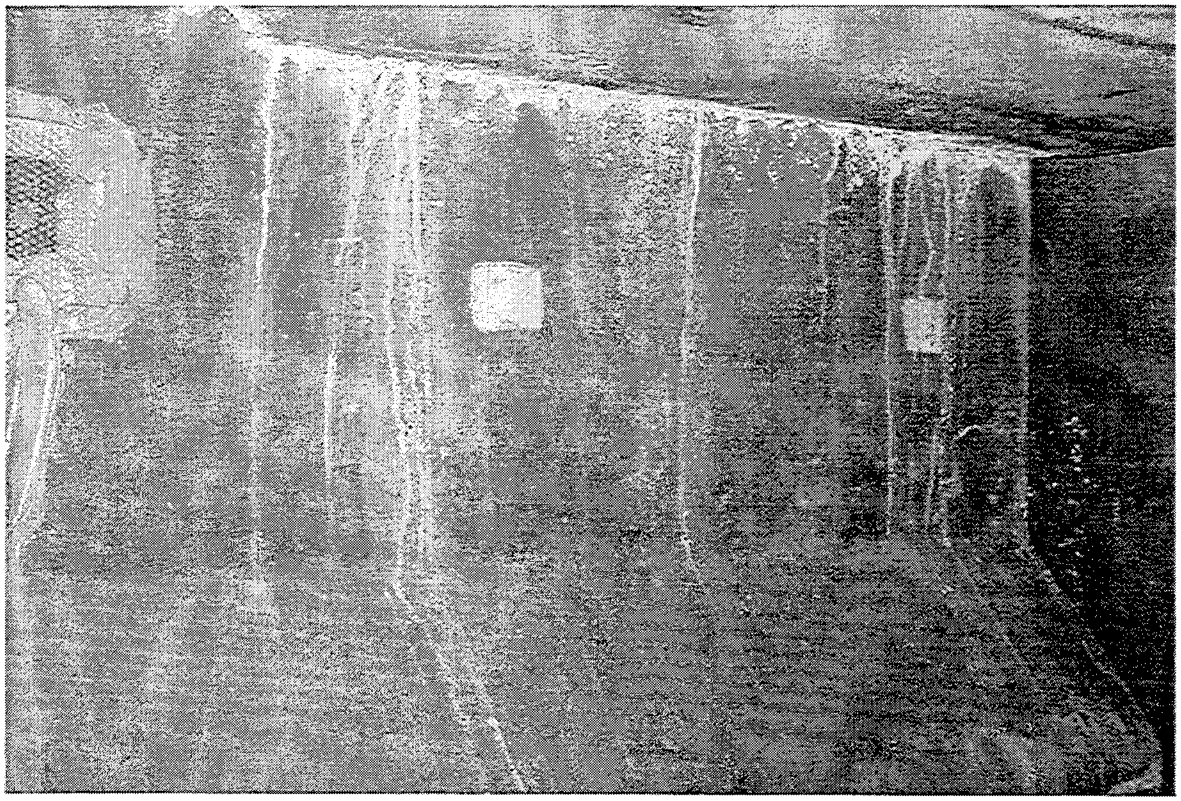

Photo 9. Beam 10, east side. Corrosion products forming from leaks in deck or at joint.

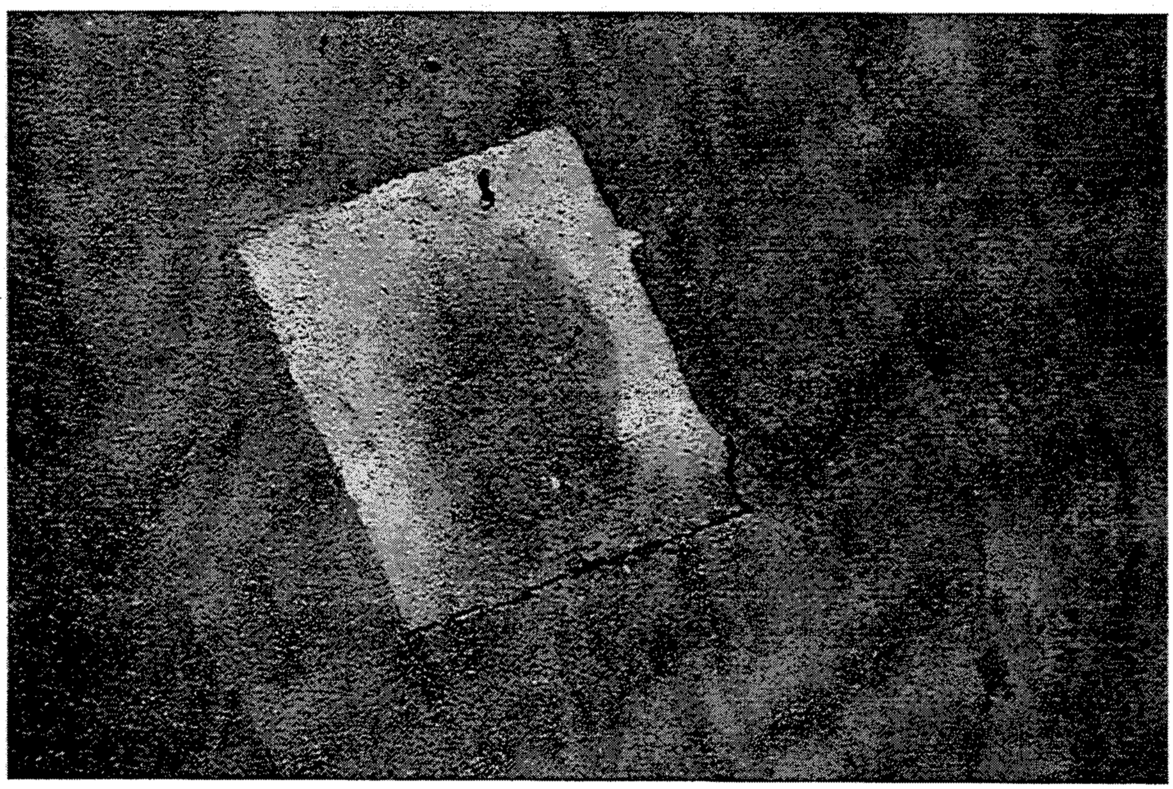

Photo 10. Water short across concrete to anode.

Conclusions and Recommendations

Evaluation of the three different types of "spray on" anodes for galvanic cathodic protection indicate that the systems do not offer any improved amount of protection to the pre-stressing strands when compared to beams that were not treated. Results from the corrosion potential surveys indicate that the systems are not protecting the steel. It appears that the anodes do not develop enough current necessary to drive the ion exchange to arrest the corrosion process. An additional survey is proposed for spring of 2002 to evaluate the anode performance. Several environmental factors as well as equipment factors which may have affected the test results will be evaluated. A main concern is the effect of water, used to moisten the surface of the concrete, bridging across the anode to form a localized short in the system. This will be addressed by using a highly conductive multi-purpose electrolyte gel to ensure conductivity. Additionally, a smaller diameter copper-copper sulfate half-cell will be evaluated to reduce the chances of bridging across the anode.

Presently, it appears that the anodes do not develop enough driving current to perform the ion exchange at the concrete-rebar interface. Until the current demand can be addressed, it would not be beneficial to the Department to pursue additional galvanic cathodic protection research.